Publication number DL-51

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OPERATING CHARACTERISTICS

DANA DATA AMPLIFIERS

mdl. 2000, 2100 & 2200

DANA™

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CONTENTS

(Note: The material in this publication consists of selected sections from the Instruction Manual for Dana Model 2000, 2100 and 2200 Data Amplifiers.)

Section		Page
1.	Specifications	1.1
2.	Description	2.1
6.	Operational Description	6.1
7.	Evaluation of Operating Characteristics	7.1
7.1.	Output	7.1
7.2.	Gain	7.2
7.3.	Gain Measurement	7.3
7.4.	AC Gain Measurement	7.4
7.5.	Linearity	7.5
	7.5.1. High Frequency Linearity	7.6
7.6.	Noise	7.7
7.7.	Chopper Intermodulation	7.7
7.8.	Bandwidth	7.8
7.9.	Slew Limiting	7.8
7.10.	Rise Time	7.8
7.11.	Step-Function Settling Time	7.9
7.12.	Overload Recovery	7.9
7.13.	Common Mode Rejection	7.9
7.14.	Common Mode Voltage	7.10
7.15.	Common Mode Impedances	7.10
7.16.	Signal Source Impedance	7.10
7.17.	Signal Source Unbalance	7.11
7.18.	Common Mode Coupling in Input Cables	7.13
7.19.	Input Impedance	7.13
7.20.	Zero Drift	7.13
7.21.	Offset Current	7.14

ILLUSTRATIONS

Figures: Page

1.1. Dimensional Drawing 1.2
2.1. External Three-Quarter View 2.1
2.2. Front Panel Controls 2.2
6.1. Block Diagram 6.1
7.1. Two-Resistor Network for Damping Galvanometer 7.2
7.2. Test Setup For DC Gain Measurement 7.4
7.3. Test Setup For AC Gain Measurement 7.5
7.4. Lissajous Figures 7.6
7.5. Signal-Source Impedances 7.11
7.6. Effect of Guard on Long Cables 7.12

SPECIFICATIONS

All specifications apply for 0 to 350 ohm signal sources, in any unbalance.

OUTPUT

Full scale	±10 volts
Over range	20% nominal
Load current, milliamperes	Mods. 2000 & 2100: 0 to 10. Mod. 2200: 0 to 100
Impedance, milliohms	Mods. 2000 & 2100: 250. Mod. 2200: 100
Capacitive load	Mods. 2000 & 2100: 0 to 0.008 mfd to full scale (0 to 0.02 mfd will cause no instability) Mod. 2200: 0 to 0.08 mfd to full scale (0 to 0.2 will cause no instability)

LINEARITY	±0.01%
BANDWIDTH	±1 db, 0 to 20 kc
COMMON MODE REJECTION	110 db dc to 60 cps, at gain of 1000, up to ±6 volts dc, or peak ac
GAIN: Option A	30 to 100; 100 to 300; 300 to 1000; 1000 to 3000 with slight overlap. (Gain resolution and stability ±0.25%)
Option B	30; 100; 300; 1000 with single vernier for ±2% adjustment from nominal. (Gain resolution and stability ±0.01%)
Option C	30; 100; 300; 1000 with no vernier. (Gain accuracy ±0.1%; stability ±0.01%)
NOISE REFERRED TO INPUT	4 uv rms, full bandwidth - at gain of 1000
INPUT IMPEDANCE	10 megohms
STEP FUNCTION SETTLING TIME	100 microseconds max to ±0.01% of final value
OVERLOAD RECOVERY	1 millisecond recovery to 0.01% of final value, from 10 v input overload of any duration
SHORT CIRCUIT PROTECTION	Fail-safe feature limits current to approximately 15 milliamperes for Mods. 2000 & 2100; to approximately 120 milliamperes for Mod. 2200; unit returns to normal operation after excessive load or short is removed

ZERO DRIFT (MAXIMUM)

Constant temperature	±0.02% full scale in 200 hours
Per C° change	±0.001% full scale and ±1 microvolt

TEMPERATURE RANGE

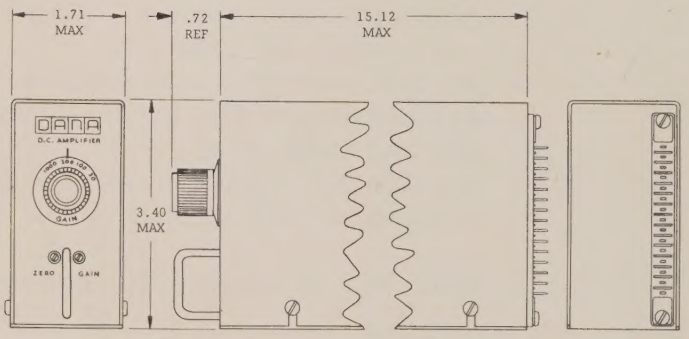
Operating	0 to +50°C
Storage limits	-20° to +85°C

POWER REQUIREMENTS . . . . . 105 to 125 volts rms; 50 to 400 cps; Mods. 2000 & 2100: 4 watts max, Mod. 2200: 6 watts max

DIMENSIONS . . . . . Mods. 2000 & 2100: 3.40" h x 1.71" w x 15.12" d or 10 per 3-1/2" EIA rack. Mod. 2200: 3.40" h x 3.29" w x 15.12" d or 5 per 3-1/2" EIA rack

WEIGHT . . . . . Mod. 2000: 2.2 lbs; Mod. 2100: 1.0 lb; Mod 2200: 4 lbs

Models 2000 and 2100



Model 2200

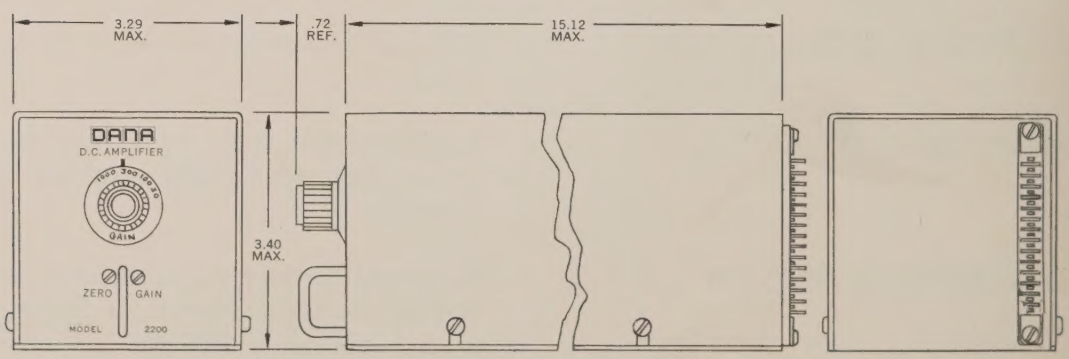
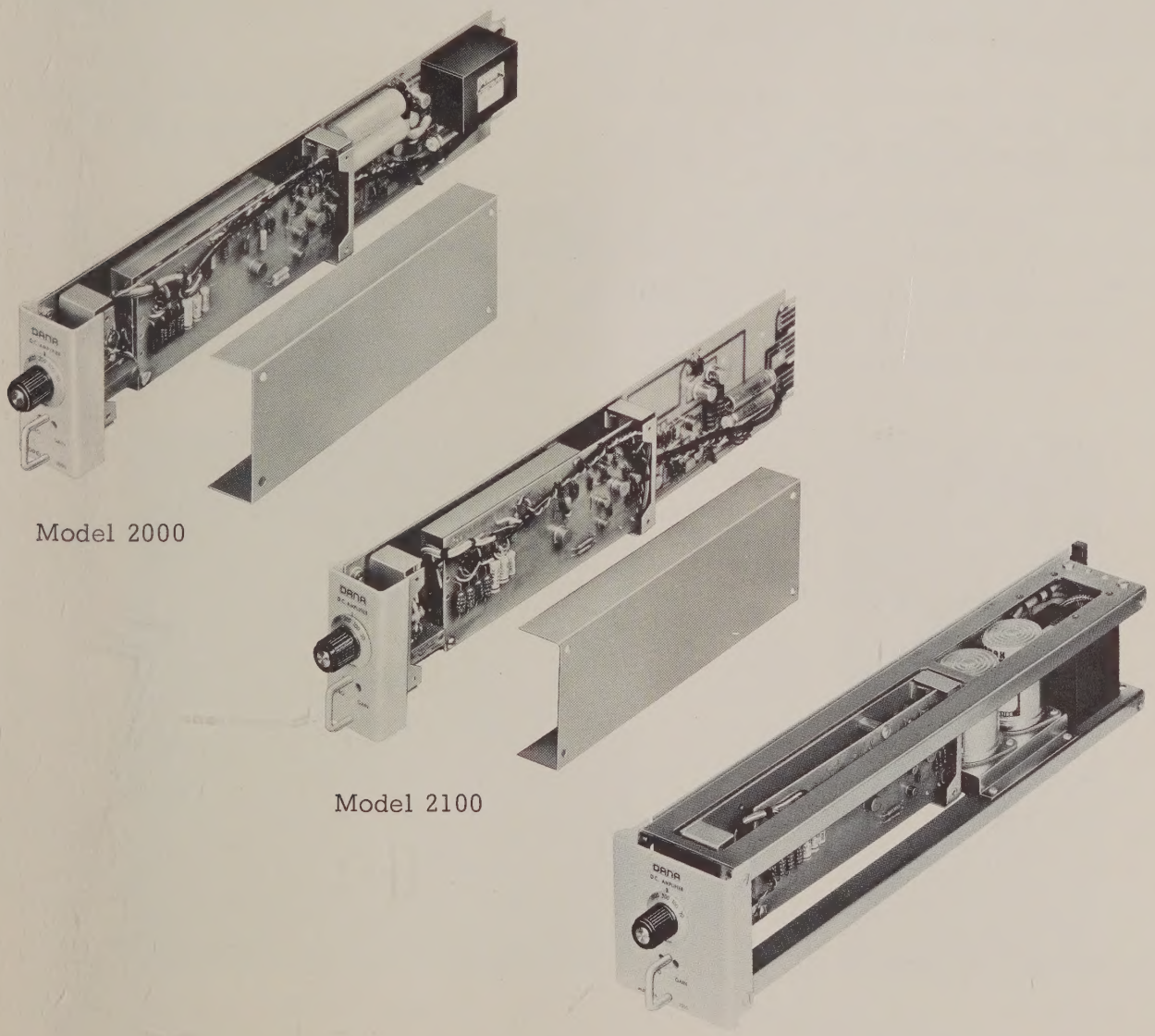


FIGURE 1.1. Dimensional Drawing

2. DESCRIPTION

The Dana Data Amplifier (Figure 2.1) is an all solid state, wideband, differential, low-level dc amplifier with integral power supply.

The unit is designed for general use in test instrumentation and data acquisition systems. It is especially suitable as a preamplifier for analog magnetic tape or oscillographic recorders.



Model 2000

Model 2100

Model 2200

FIGURE 2.1. External Three-Quarter View

The first general purpose instrument of its type, the Dana Amplifier may be used as either a differential or single-ended amplifier. In the latter case, no special plug-ins or switches are required. Wide bandwidth (0-20 kc), fast settling time, and high common-mode rejection add to its versatility.

The amplifier features excellent linearity, high gain accuracy, low drift, and low noise.

Extreme reliability and long life stem from the basic design. Mechanical choppers and other moving parts have been eliminated. New design concepts have resulted in simplified circuits that minimize the total number of components. Silicon semiconductors are used exclusively.

The Dana Amplifier is contained within a compact package. Ten Model 2000 or 2100 units, or five Model 2200 units, will fit in the width of a standard EIA relay rack. Overall height is only 3.40 inches.

There are three front-panel controls (Figure 2.2) used in operation: a gain selector switch and two screwdriver adjustments. One adjustment is for zero; the other, a vernier to interpolate between gain steps.

Models 2000 and 2100

Model 2200

FIGURE 2.2. Front Panel Controls

6. OPERATIONAL DESCRIPTION

The design concepts which make these amplifiers possible are totally new. Dana has applied for several patents on these concepts. The amplifier contains an encapsulated section called the Signal/Common Mode Resolver. The instrument also contains two direct coupled amplifiers and a set of power supplies.

One of the direct coupled amplifiers is called the Signal Amplifier. The one output is taken from this amplifier -- output voltage, currect characteristics, short circuit proof feature, etc., are all established by this unit. Its output voltage is fed back to the S/CM Resolver, the combination comprising a potentiometric feedback amplifier. The gain is established solely by precision resistors inside and outside the S/CM Resolver.

There are two gain controls: coarse, which is switched; and fine, a continuously adjustable vernier. The coarse gain is established by a single resistor, as can be seen in the block diagram (Figure 6.1). However, each coarse step changes the feedback constant H, and consequently, the loop gain (KH).

Optimum performance is realized only when the loop gain is held constant. Therefore, an auxiliary or forward gain control is ganged to the coarse gain control. This auxiliary control maintains the loop gain constant. A minor variation of the

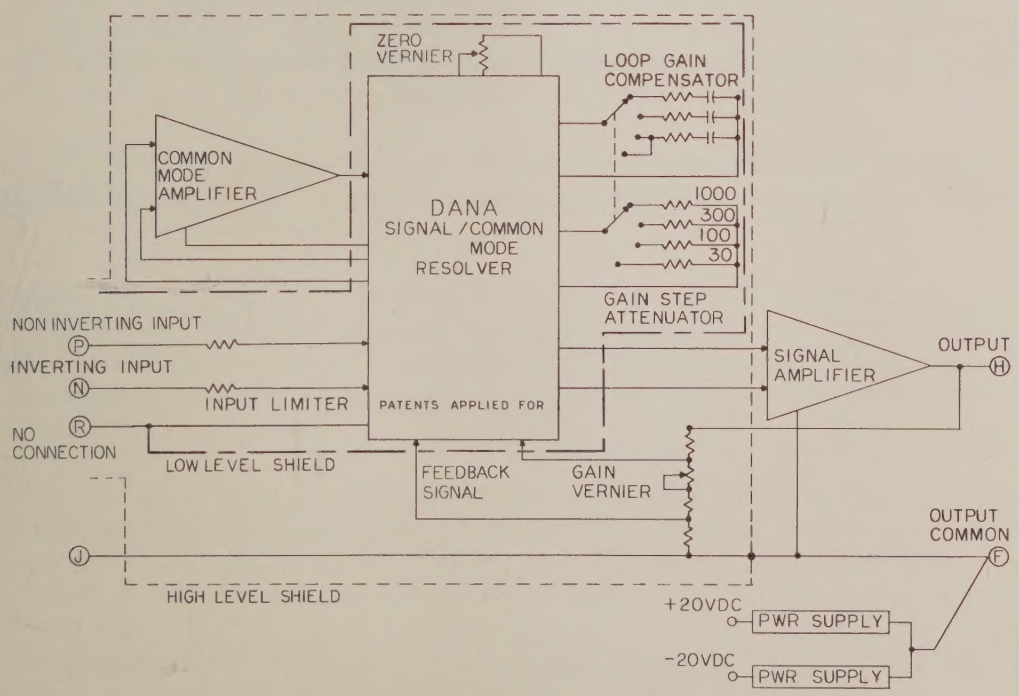


FIGURE 6.1. Block Diagram

high frequency characteristics accompanies changes in the gain vernier. These effects are negligible for ±2% type changes, but are significant for spans in the order of 3 to 1.

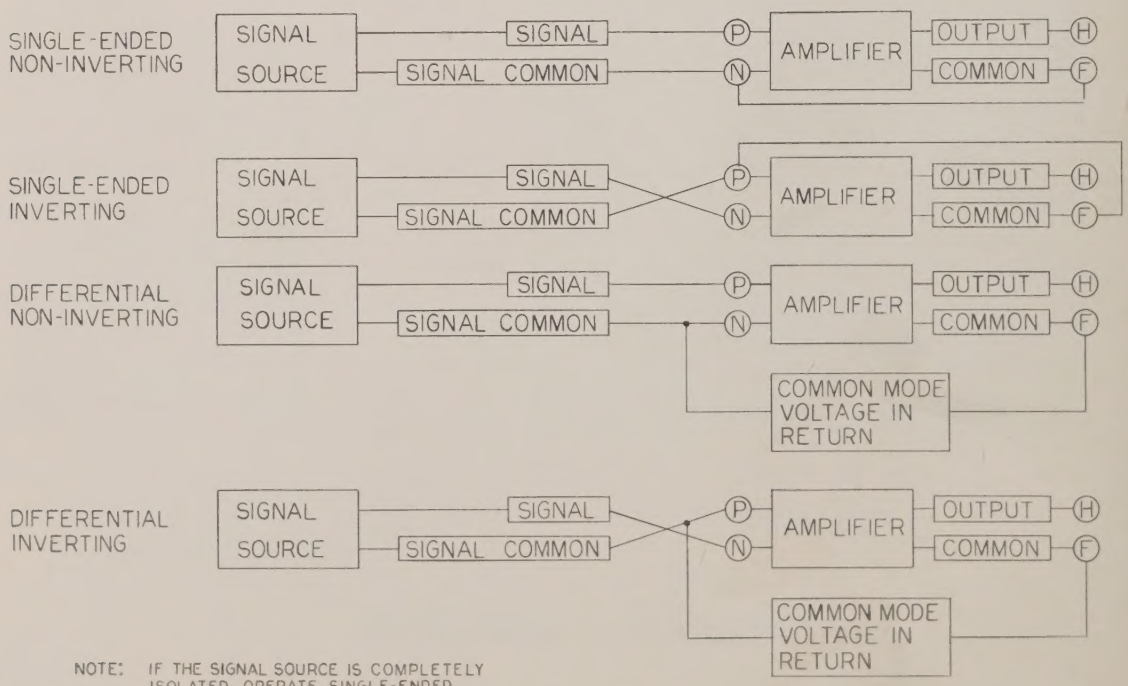
Also associated with the signal amplifier is a zero adjustment. When this adjustment is properly set, the amplifier output zero is independent of the coarse gain control. This should be checked occasionally by shorting the input and switching from maximum to minimum gain. If necessary, readjust at the minimum gain setting.

A second direct coupled amplifier, the Common Mode Amplifier, is used in conjunction with the S/CM Resolver. The amplifier has no controls or adjustments. However, to avoid saturation, the peak value of V_{cm} should not exceed 6.0 volts.

The function of the Signal/Common Mode Resolver is to resolve the two input signals into signal and non-signal components. This resolution is performed with the accuracy of an analog computer. There is no degradation of gain accuracy, linearity or noise injected by transformers or open loop modulator-demodulators. Since this resolution is performed by computer-like circuits, the resolution is independent of frequency at dc and at low audio frequencies.

It may be observed that the S/CM Resolver is enclosed in an electrostatic shield called the Low Level Shield. This shield is electrically driven by circuits internal to the Resolver. There should be no external connection made to this Low Level Shield, although pins (R) and (M) are brought out for test purposes.

The Dana Amplifier can be used in any of the four operating modes illustrated below.



NOTE: IF THE SIGNAL SOURCE IS COMPLETELY ISOLATED, OPERATE SINGLE-ENDED

7. EVALUATION OF OPERATING CHARACTERISTICS

Tabulated specifications provide a concise, quantitative means for relating an instrument to a potential application. It is also a means for comparing the relative suitabilities of competitive instruments for a given application.

However, an abbreviated description such as this must be used cautiously. Developments in the electronic industry are so rapid that terminology, test conditions, etc., are neither standardized nor binding. Consequently, different manufacturers and different users often apply the same term in different ways, or use different terms to describe the same quantity.

Dana Laboratories adheres to generally recognized standards when they are applicable. However, there are many test procedures and parameters that are neither standard nor well defined. The purpose of the following commentary is to convey to the user the exact meaning of the terms used by Dana in the design, manufacturing, and testing of Data Amplifiers.

7.1 OUTPUT

In the case of the Dana Amplifier, "output" is defined as the voltage between the OUTPUT and COMMON terminals.

These two terminals are isolated from the amplifier chassis, but are not guarded. Since there is considerable capacity between COMMON and the system ground, it is necessary to ground the COMMON terminal (F), not the output terminal (H), if the output signal is referenced to ground.

The COMMON terminal is common both to the output and to the internal dc power supplies. All voltages except the input signal are measured relative to this point.

The full scale output of the amplifier is -10 volts to +10 volts dc, peak ac or any combination, at frequencies up to 20 kc. Specifications such as gain accuracy, linearity, and output impedance apply to outputs within this full scale limit. At frequencies from dc to nearly 20 kc, there is a nominal overscale capability of 20%.

The Model 2000 or Model 2100 will drive a load current of 10 ma peak. At 10 volts output, this corresponds to a load of 1000 ohms dc resistance or a 0.008 uf capacitance at 20 kc. If the load draws this current at a lower voltage, nearly normal operation will be maintained, but with some loss of gain accuracy.

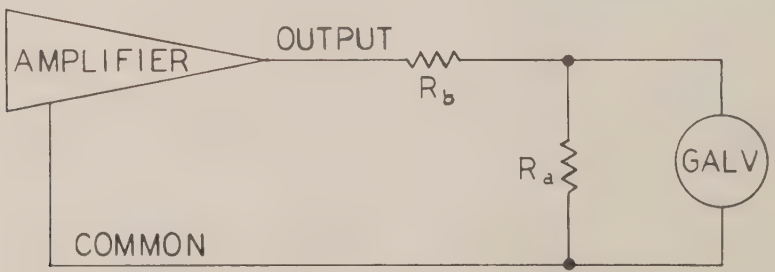
The Model 2200 will drive a load current of 100 ma peak. At 10 volts output, this corresponds to a load of 100 ohms dc resistance or a 0.08 uf capacitance at 20 kc. If the load draws this current at a lower voltage, nearly normal operation will be maintained, but with some loss of gain accuracy.

A capacitive load of up to 0.02 uf for the Model 2000 or 2100, and 0.2 uf for the Model 2200, can be driven with no instability or effect on dc gain, linearity, or other operating specifications. Under these conditions, however, the amplifier cannot be driven at full scale amplitude at frequencies above 8 kc due to dynamic saturation (see Section 7.9 -- Slew Limiting). Also, at frequencies of 8 kc and above, gain accuracy is impaired, even for small signals.

If a low-resistance load, such as a recording galvonometer with a typical 25-ohm resistance, is to be driven, series resistance should be added so that the full scale of the recording instrument corresponds with amplifier full scale. This increases the accuracy of the instrumentation system and also serves to protect the recording instrument from damaging overload. Should the load require a particular driving resistance, such as an external damping resistance, a simple two-resistor network is needed between the amplifier and the load (see Figure 7.1).

7.2 GAIN

Unless otherwise specified, the term "gain" means the ratio of the magnitude of $\triangle Vo$ divided by the magnitude of $\triangle Vi$, where Vo is the output signal and Vi is the input (refer to Figure 6.1). In the inverting mode, gain also means a change from minus full scale to plus full scale.



VALUES OF R_a AND R_b ARE DEFINED BY:

$$R_a = \frac{R_b R_d}{R_b - R_d}$$

AND

$$R_b = \frac{10V}{I_{FS}\left(1 + \frac{R_g}{R_d}\right)}$$

WHERE: R_d = REQUIRED EXTERNAL DAMPING RESISTANCE
R_g = GALVANOMETER RESISTANCE
I_{FS} = GALVANOMETER FULL SCALE CURRENT

FIGURE 7.1. Two-Resistor Network For Damping Galvanometer

Linearity is so great that gain is essentially independent of Vo. Since the Dana unit is a negative feedback amplifier, the gain is determined almost entirely by the ratio of resistors in the feedback network. The specifications are valid for any gain from 20 to 1,000. A small degradation occurs in the 1,000 to 3,000 span. Considerable latitude exists in the number and value of gain steps that can be supplied between the limits of 20 and 3,000. Three standard options are available. Quotations will be made for other arrangements.

Gain Option A provides a continuously variable gain from 30 to 3,000 in four ranges: 30-100, 100-300, 300-1000 and 1000-3000, with a slight overlap between ranges. The resolution and mechanical stability of the continuously variable control limits the gain resolution of the amplifier to ±0.25%. However, Option A is particularly useful for applications where the load has a limited dynamic range, as in the case of magnetic tape recorders or recording oscillographs. In these applications, it is desirable to match the full scale of the transducer to that of the recorder. This requires either a very large number of closely spaced gain steps or a continuously adjustable gain. At the same time, the limited dynamic range makes it impossible to detect errors in the order of 0.25%. Because this vernier varies the feedback ratio in the amplifier, the frequency response is reduced at the clockwise (high gain) end of the span.

Gain Option B provides four fixed values of gain: 30, 100, 300, and 1000, with a vernier to adjust the fixed values ±2%. Gain resolution and stability ±0.01%.

Gain Option C is identical with Option B, but without the vernier adjustment. Each of the four settings is accurate to within ±0.1% of the nominal value and is stable to within ±0.01%. Options B and C are recommended for applications with a high dynamic range (full scale/minimum resolvable signal). Typical is a digital data system with a dynamic range of 10,000 to 1.

7.3 GAIN MEASUREMENT

Because the Dana unit can be operated as a single-ended amplifier, very accurate gain measurements can be made using the test setup shown in Figure 7.2.

The signal source (battery in Figure 7.2) need not be highly accurate or stable. It should be adjusted to be approximately 10 volts.

However, the voltage divider must be more accurate than the amplifier gain which is to be measured.

The following procedure should be followed in measuring gain:

1. Set switch S to position 1. This sets the input to the amplifier at zero volts. Adjust the zero on the amplifier (or null detector) until null is read.

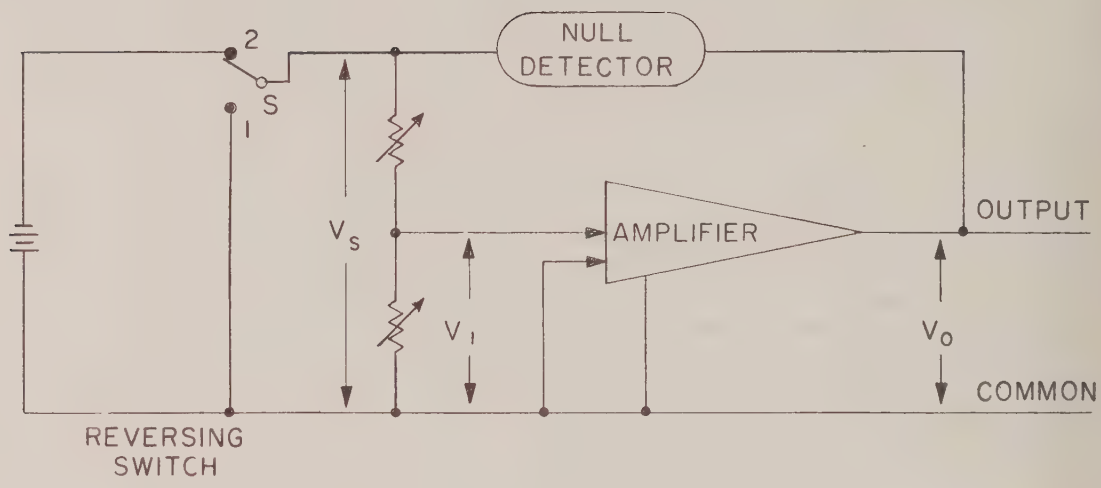


FIGURE 7.2. Test Setup For DC Gain Measurement

2. Set switch S to position 2. Adjust the voltage divider until null is again read.
3. Calculate the amplifier gain from

$$K = 1/h$$

where
K = amplifier gain
h = voltage ratio of divider

The null detector is sensitive to either real changes of gain or, in ac measurements, to quadrature signals. The latter are normal, due to a slight phase lag in the output. The phase lag is proportional to frequency, limiting this test to dc or low frequency ac measurements.

7.4 AC GAIN MEASUREMENT

The gain-measurement technique described above can be extended to ac if the phase lag in the amplifier is compensated and a suitable null detector used.

The output of the bridge transformer is set to a null at the fundamental by adjusting both the real component (h) and the quadrature component (R1) to zero.

If the term ωT_1 is small, the effect on magnitude of the quadrature signal can be ignored, and $K = 1/h$. For example, if $\omega T_1 = 0.1$, the reference input to the bridge transformer is $1/\sqrt{1^2 + (0.1)^2} = 1/\sqrt{1.01}$ or approximately 0.995. If not compensated, a gain measurement error of approximately +0.5% results. This will occur at a frequency above 5 kc.

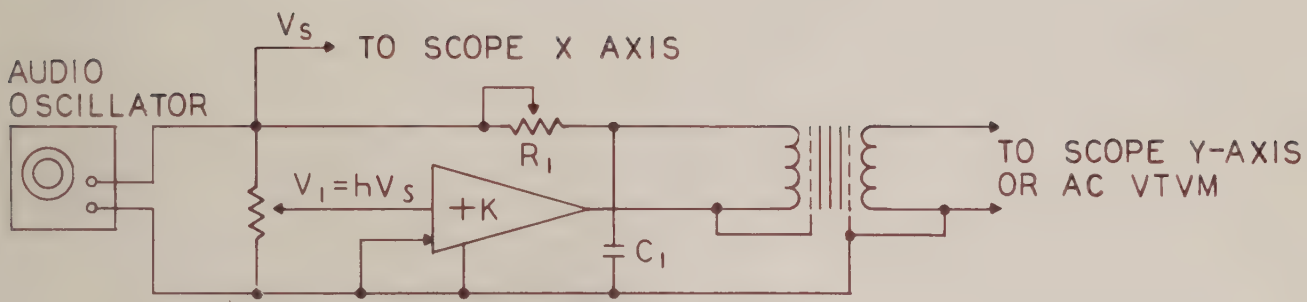


FIGURE 7.3. Test Setup For AC Gain Measurement

When an exact measurement is desired, the following relation holds:

$$K = (1/h)/\sqrt{1 + (\omega T)^2}$$

where $\omega = 2\pi f$; $T = R_1 C_1$

A Lissajous figure on the oscilloscope is particularly helpful in balancing the fundamental to a null because in-phase, quadrature, harmonics, and other signals can be visually separated, as shown in Figure 7.4.

Because of noise, harmonics, etc., a true null can never be reached. If a vacuum-tube voltmeter is used instead of an oscilloscope, adjust the real component, then the quadrature component, to produce a minimum output, repeating till no further improvement is possible.

7.5 LINEARITY

Ideally, gain should be independent of the magnitude of the output voltage from minus full scale to plus full scale. Since the Dana Amplifier's departure from this ideal is small, the null balance method of the gain measurement above is again used. Linearity can be measured immediately after gain measurement.

FIGURE 7.4. Lissajous Figures

Steps 1 and 2 are followed as before. The input voltage is then varied from minus full scale to plus full scale, and the peak reading of the null detector recorded. The linearity in percent can be calculated as follows:

$$\frac{\text{peak null detector reading (volts)} \times 100}{\text{full scale (10 volts)}}$$

7.5.1 HIGH FREQUENCY LINEARITY

It is commonly understood that nonlinear distortion will generate harmonics, second, third, fourth, etc. of the driving frequency. It is less commonly realized that a dc offset is also produced by nonlinear distortion. The Dana Amplifier will be offset by less than 0.01% of the peak value of a 2000 cps output, provided that the peak is not large enough to saturate the amplifier. This offset will increase with frequency, but in a simple controlled manner to at least 20,000 cps.

This is encountered as a practical problem when the amplifier must be used wideband to drive a magnetic tape recorder or other wideband load, and the output is post filtered, then the dc component measured digitally. In extreme cases separate amplifiers might be necessary with at least some prefiltering used with the dc channel.

This offset is normal to any dc amplifier. The diode equation, which is the basis of all transistor amplification, is nonlinear. However, these amplifiers are designed to be as nearly linear as practical when operated open loop; in addition

the linearity is further refined by negative feedback. The magnitude of the negative feedback decreases with increasing frequency, which permits this effect to increase.

At large amplitudes and frequencies beyond 20 kc a form of saturation may occur which is called slew limiting (see Section 7.9). Whenever this or any other saturation occurs, the offset is large and uncontrolled. The usefulness of data taken under these conditions is extremely questionable. If slew limiting is encountered, prefiltering is mandatory.

7.6 NOISE

Noise in a data amplifier is a complex function of bandwidth, gain, loop gain and other factors. The stabilization of large values of loop gain always produces a high degree of noise compared with open or low loop-gain amplifiers, such as radar amplifiers. Excess noise is unavoidable, particularly in the higher frequencies near the limit of the bandwidth.

In addition to the inevitable random noise, there may be systemic noise at the line or chopper frequencies of their harmonics. In the Dana Amplifier, systemic noise is so nearly nonexistent as to be undetectable in the total noise, except by very sensitive narrow-band analyzers. Overall noise is random, but not uniformly weighted with respect to frequency.

Noise specifications are based on the total noise from an arbitrarily low frequency (10-20 cps) to the limit given. If less than the full amplifier bandwidth is specified, a single-pole, low-pass filter is assumed between the amplifier output and the noise-measuring instrument. The noise bandwidth is based on power transmission, not voltage. The noise power bandwidth, in cycles per second, of a single-pole filter is $(1/4\ T)$ not $(1/2\pi T)$ (conventional -3 db point), where $T = RC$ or L/R.

A true rms measurement is desirable, but the freedom from systemic noise makes reasonably accurate measurements possible with either an rms-calibrated average voltmeter or an oscilloscope (rms is approximately 1/6 the peak-to-peak value observed on the oscilloscope).

Noise on 1 kc bandwidth is 1 uv rms. On wide band, no spikes are present and noise is under 3 x rms spec 98% of the time (3 sigma).

7.7 CHOPPER INTERMODULATION

At signal frequencies harmonically related to the chopper in a chopper-stabilized amplifier, beat notes are produced. For example, at an $(2fc \pm x)$ input, an x frequency output is produced by "chopper intermodulation." The Dana Amplifier does not exhibit this phenomenon, and thus does not require this type of specification.

7.8 BANDWIDTH

Bandwidth is one measure of an amplifier's ability to respond to rapidly changing signals. There are other measures, including rise time and settling time. Each measure has its application, and is not interchangeable with the others.

Bandwidth in the Dana Amplifier is defined as the maximum frequency at which the gain remains within a specified tolerance from the dc gain. For example, from dc to 20 kc the amplifier will stay within ±1 db (within 89 to 112% of dc gain). At low amplitudes, the Dana Amplifier is flat to ±3 db to approximately 70 kc on step gains, or at the low end of the adjustable gain settings.

7.9 SLEW LIMITING

Many amplifiers, including the Dana unit, have a form of dynamic saturation called "slew limiting." The effect is to put a maximum limit on the rate-of-change of the output voltage, or dV/dt, and this in turn limits the peak voltage at a given frequency.

In certain cases, slew limiting may be due to an output current limit and a capacitive load so that: $dV_o/dt = I/C$.

For example, if I = 10 ma and C = 0.02 uf, then dV_o/dt maximum = 500,000 volts/sec or a peak voltage of 4 volts at 20 kc.

Without a capacitive load the slew rate of the Dana Amplifier exceeds 10^6 volts/sec.

It should be noted that slew limiting may be the result of factors both internal and external to an amplifier. One effect of slew limiting is to cause the response time to increase with the magnitude of a step function.

7.10 RISE TIME

If the input to an amplifier is a step function, the output will be a continuous function, having a finite "rise time." Rise time is defined, in the case of the Dana Amplifier, as the interval between the instant the output passes through 10% of the step and the instant the 90% point is passed.

If the amplifier is not slew limited, the rise time is inversely proportional to bandwidth. A single RC is typical of amplifier pass bands.

$$\begin{aligned} \text{Rise time} &= (\log_e 0.9 - \log_e 0.1)\, RC \\ &= 2.2\, RC \\ &= 1.1/\pi B \end{aligned}$$

or approximately 0.35/B

where B = bandwidth in cycles per second to -3 db

The exact form of the response will cause only minor variations in the relationship between rise time and bandwidth. However, slew limiting may greatly increase the rise time for a given small-signal bandwidth.

7.11 STEP-FUNCTION SETTLING TIME

The rise time specification is of limited use in the design of digital systems since rise time indicates only when the signal is within 10% of its final value and a far more accurate approximation is required. In digital work, a much longer period, defined as settling time, must be used. Settling time is measured to a small residual error, such as 0.01%.

Settling time is far more complex than rise time. In addition to a small-signal bandwidth and slew limiting, the exact form of the band limit is significant, as is the response at much lower frequencies.

An amplifier often appears to settle in a few microseconds but then creeps an additional 0.1 or 1%, finally settling after many milliseconds. The best clue to real settling time is the overload recovery time, because both are related to the longest time constant in the amplifier.

Thus, though an amplifier appears to settle in a few microseconds, if the overload recovery time is 300 milliseconds, the settling time may be in the order of 30 milliseconds.

7.12 OVERLOAD RECOVERY

The Dana Amplifier will recover to within ±0.01% of full scale within 1 millisecond, following the return from a 10 volt input overload of any duration. This results in an assured settling time of only 100 microseconds in the Dana Amplifier.

The amplifier output is short-circuit proof. If the output is shorted and then opened, recovery is similar to recovery from an input overload.

7.13 COMMON MODE REJECTION

Common mode voltage is an interference frequency encountered in data amplifiers. Common mode rejection is a quantitative measure of the amplifier's ability to suppress this form of interference.

Common Mode Rejection (CMR) is defined as the ratio of the common mode voltage V_{cm} to a fictitious input signal v_{cm} which would produce the same effect on the output as V_{cm}.

	V_{cm}	=	V_o/K
when	V_o	=	output voltage due to V_{cm}
	K	=	amplifier gain,
then	CMR	=	$1.1V/K/V_{cm}$

It is necessary to use the magnitude of V_o, since V_o may have any phase relative to V_{cm}.

Input cables, connectors, patch panels, and scanners all contribute to V_{cm}, the components adding vectorially. It is conventional to specify this CMR of the amplifiers above. Even in this case, v_{cm} has two components, one independent of signal source impedance and one which is due to finite common mode loading impedances. Operated from a short circuit, the Dana amplifier CMR is typically several million to one. Under realistic conditions, such as a 350 ohm unbalance, CMR is 316,000:1. This can also be expressed as 110 db, where CMR in db = 20 log (V_{cm}/v_{cm}).

7.14 COMMON MODE VOLTAGE

If the two inputs are shorted, V_{cm} is obviously the voltage between the shorted inputs and COMMON. The identification of V_{cm} when the inputs are not shorted makes use of the fact that most differential amplifiers have unsymmetrical inputs. One of these is labeled the "input"; the other, the "input common." V_{cm} is defined as the potential difference between input common and output common.

In the case of the Dana Amplifier, V_{cm} is taken as the voltage between the P input and the output COMMON. This convention is somewhat arbitrary because the input is virtually symmetrical.

7.15 COMMON MODE IMPEDANCES

The normal mode input impedance between the N and P inputs can be temporarily ignored because it loads V_i and V_{cm} identically.

Any differential amplifier loads each input terminal to output common. This loading is conventionally very unsymmetrical, with one side being a high impedance, and the other an extremely high impedance. In the Dana Amplifier, both input terminals have an extremely high impedance to COMMON. Moreover, the impedance is due to internal feedback, not to "guarding." Because the common mode impedances are extremely high, no balance control is needed or furnished.

The significance of common mode impedances is only in relationship to the signal source impedances (see Figure 7.5).

7.16 SIGNAL SOURCE IMPEDANCE

A signal source with V_{cm} can be resolved into at least two internal impedances: one in series with the signal, and the other in series with the signal common.

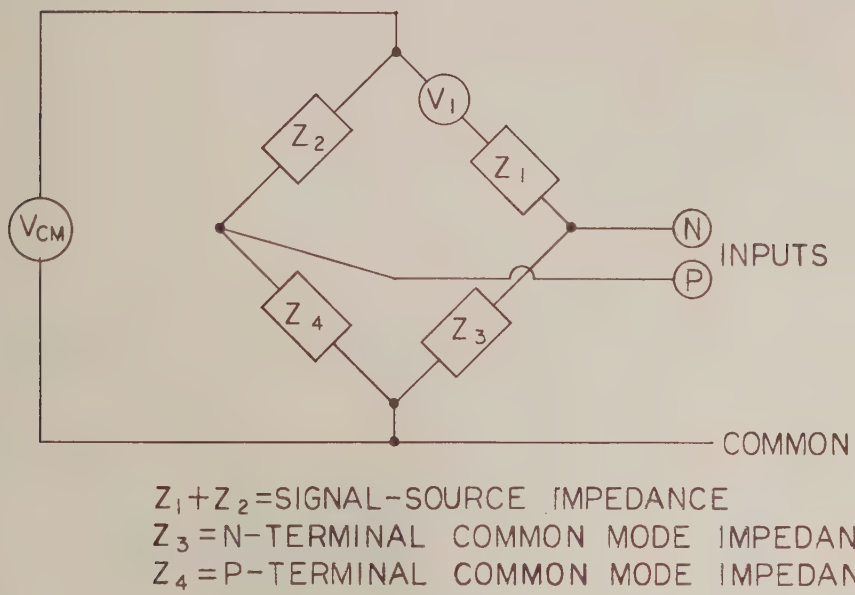


FIGURE 7.5. Signal-Source Impedances

If the amplifier is unsymmetrical, the ratio of these impedances is not significant. The concept of balance is misleading. Only the magnitude of the signal common impedance is relevant.

If the amplifier is symmetrical, the fractions of V_{cm} coupled into the two inputs tend to cancel. This is because the four impedances can be considered a bridge, as shown in Figure 7.5.

A very high CMR can be realized if such a bridge is manually balanced, but the balance is critical and often unstable.

In the Dana Amplifier, the magnitude of the coupling is very small. Although symmetrical in nature, this balance is not exploited. The CMR specification is stated as being without adjustments of any kind; in fact, there are no adjustments provided.

7.17 SIGNAL SOURCE UNBALANCE

The input signal to any differential amplifier must be considered as three terminals. There will be a finite impedance between any two terminals, even though the impedance may be very high. For simplicity, ignore the normal mode input impedance, which will load signal and coupled common mode equally. Then the common mode impedances and signal source impedances can be drawn as a bridge, as in Figure 7.5.

A fraction of the common mode voltage is coupled into the signal (unless Z_1 and Z_2 are shorted, which would be an unrealistic condition). Then:

$$\frac{V_{cm}}{V_{cm}} = \frac{Z_2}{Z_2 + Z_4} - \frac{Z_1}{Z_1 + Z_3}$$

or

$$\frac{V_{cm}}{V_{cm}} = \frac{Z_2}{Z_4} - \frac{Z_1}{Z_3}$$

because $Z_2 \ll Z_4$, $Z_1 \ll Z_3$

In the Dana Amplifier, Z_4 and Z_2 are nearly equal and inherently very large -- not less than 350 megohms, which is equivalent to 7.5 picofarads at 60 cps. In the electromagnetically coupled amplifiers, Z_4 is typically the impedance of 2700 picofarads or more, and Z_3 is virtually an open circuit. This value of capacity has an X_C of one megohm at 60 cps. If Z_2 is 1000 ohms, the CMR is 1,000,000 to 1,000 or only 1000 to 1. Large values of CMR are obtained only by adding an extra shield or "guard" and virtually eliminating any V''_{cm} between the signal and the guard (Figure 7.6).

The Dana instruments do not need or use the guard internally. The CMR specification does not depend upon either the user's ability to find a suitable guard-driving voltage, nor on twiddling Z_2 and/or Z_4 to balance the coupling to a low value of CMC.

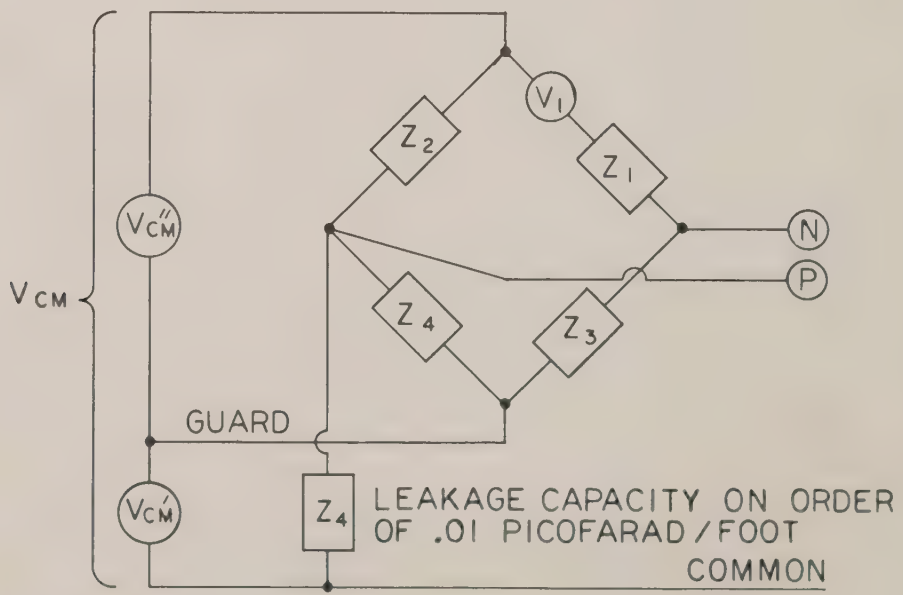


FIGURE 7.6. Effect Of Guard On Long Cables

7.18 COMMON MODE COUPLING IN INPUT CABLES

A high CMR in the amplifier is necessary but can be destroyed by input cables, external to the amplifier. The only way to keep signal-to-ground capacity very small is to shield the wires from ground; that is, to use an insulated, driven shield or guard. The longer the input cables to the amplifier, the more imperative is the guard.

A typical shielded cable has a much larger per-foot capacity than the amplifier common mode capacity. Common mode coupling (the reciprocal of CMR) will increase almost in direct proportion to the cable length. Driving the guard very accurately will reduce the apparent cable length (see Figure 7.6).

7.19 INPUT IMPEDANCE

The input impedance of these amplifiers is essentially a stable, passive 10-megohm dc resistance, shunted by not more than 0.0012 microfarads.

These amplifiers are designed especially to be operated from low-level transducers such as thermocouples and strain gages. The 10 megohms will cause a loading error of 0.0035% when operated from a 350- ohm strain gage. Even this minute error is absorbed by normal strain gage calibration procedures. Thermocouples usually have even lower internal resistances.

These amplifiers can be operated from high impedance sources, although the loading errors will necessarily increase. In particular, the frequency response will be degraded by the capacitive load. For example, the response will be -3 db at about 13 kc, when operated from a 10,000 ohm source.

Common mode rejection is necessarily reduced when operated from high impedances due to common mode loading, as described in Section 7.15.

7.20 ZERO DRIFT

Characteristically, zero drift is the greatest single error in data amplifiers. This drift has no effect on frequency response, linearity, and other parameters, but merely displaces the output. There are two components of drift: voltage and current. The voltage component of drift can be measured if the input is shorted, or if operation is from transducers of such low resistance as to make negligible the effect of current drift.

The Dana Amplifier drift specification, based on a 0-350 ohm signal source, is ±0.02% of full scale, or ±2 mv referred to the output in 200 hours. This is ±2000 microvolts/K, referred to the input, or ±2 microvolts when K = 1000.

In addition, the temperature coefficient specification is ±0.001% of full scale and ±1 uv referred to the input, per-degree-centigrade temperature change. This totals ±1.1 uv/per ^{o}C referred to the input at K = 1000.

7.21 OFFSET CURRENT

A portion of the zero drift is due to an IR drop in the transducer. Resistance is normal to dc output type transducers, and all dc amplifiers produce some offset current through the transducer. In the Dana Amplifier the offset current is typically less than 10^{-9} amperes from each input, returning through the transducer to common at 25^{o}C. This may change approximately ±10^{-9} amperes per degree centigrade. The Dana Amplifier drift specification is based upon a maximum source resistance of 350 ohms and includes the change in the IR drop. Higher resistance transducers may produce larger than specified drift/temperature coefficient because of this effect.

Since this current returns to common, the transducer should not be totally isolated. Any common mode dc resistance will cause an IR drop or self-generated common mode voltage. This is never a problem in the field, since 6 volts/10^{-9} amperes = 6,000 megohms; however, this effect can be encountered in laboratory testing.

Dana Laboratories hopes that the above section has helped you to understand the nature of data amplifiers such as the Dana Amplifier.

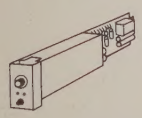
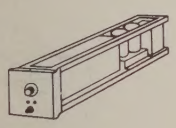
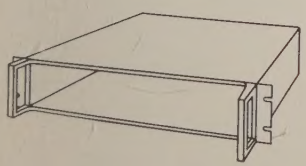
We also trust that it will help you to put the Dana Amplifier to the most effective use in your application.

DANA™

price list | A-2 | effective 1 November 1962 (supersedes price list A-1)

DANA WIDE BAND DC DIFFERENTIAL AMPLIFIERS

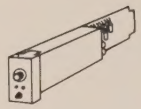
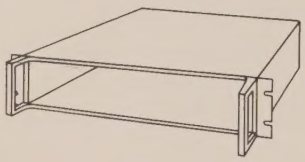
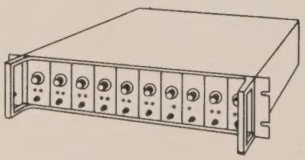
Prices are F.O.B. Santa Ana, California. Specifications and prices are subject to change without notice. Terms: Net 30 days.

MODEL 2000	**AMPLIFIER**	$510.00*
	10 ma output with integral power supply, for rack mounting Housing assembly for individual amplifier (when not intended for rack mounting) includes case mounting bracket, case, and connector. Part number 001348, $12.00	
MODEL 2200	**AMPLIFIER**	$560.00*
	100 ma output with integral power supply, for rack mounting Housing assembly for individual amplifier (when not intended for rack mounting) includes case mounting bracket, case, and connector. Part number 001513, $15.00	
MODEL 2003	**ENCLOSURE**	$250.00
	3½" x 19" rack with plugs to accommodate up to 10 amplifiers in any of the following combinations:	

Model 2000	up to 10 units. Blank panels (part number 001122, $2.00 each) available as fill-in for less than 10 units in assembly
Model 2200	up to 5 units. Blank panels (part number 001123, $3.00 each) available as fill-in for less than 5 units in assembly
Intermixed	1 model 2200 may be substituted for any 2 adjacent model 2000 units, without modification

*Extra cost of $45.00 for Gain Option A

(see footnote on next page)

MODEL 2100	**AMPLIFIER**	$440.00*
	10 ma output without power supply or case, used only in Model 2005 enclosure with shared power supply	
MODEL 2005	**ENCLOSURE WITH POWER SUPPLY**	$450.00
	3½" x 19" rack with 15 watt power supply and plugs, for use with up to 10 model 2100 amplifiers	
MODEL 2110	**AMPLIFIER ASSEMBLY**	$4,850.00
	Ten model 2100 (10 ma output) amplifiers mounted in model 2005 enclosure (3½" x 19" rack) with shared power supply	

*Gain options (extra cost of $45.00 for Option A)

Option A	Overlapping ranges of 30 to 100; 100 to 300; 300 to 1000; 1000 to 3000
Option B	30; 100; 300; 1000 with single vernier for ±2% adjustment from nominal
Option C	30; 100; 300; 1000 with no vernier

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